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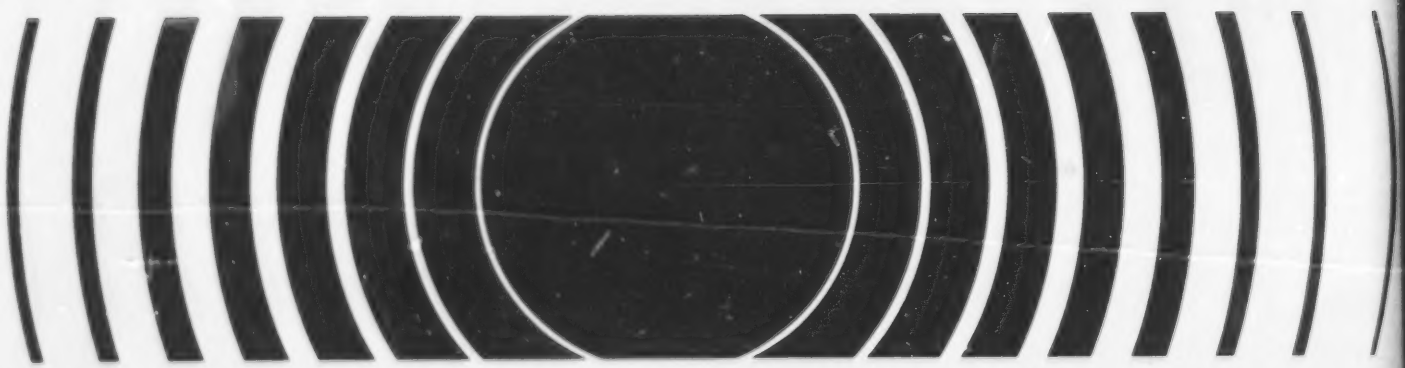

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16. ABSTRACT

Additional radiological measurements were performed during 1976 and 1977 at the Maxey Flats radioactive waste burial site. These supplement data collected during 1974 and 1975 reported in EPA-520/5-76/020.

Evaporator effluents were investigated further to better define quantities of radionuclides discharged to the atmosphere and improve decontamination factors assigned to the principal radionuclides observed in the evaporator feed: ^{3}H, ^{14}C, ^{60}Co, ^{137}Cs, ^{238}Pu, and ^{239}Pu.

On-site measurements included soil sample profiles taken to a maximum depth of 3.5 m from the trench area and from within the main washes east and south of the site. These measurements provided additional information on the near-surface lateral movement of radioactivity. Radiochemical analysis of a test-well sample showed that all measurable radioactivity was associated with the sediment in the well and the highest specific radioactivity was associated with the smaller particles ($< 5\ \mu m$).

Milk and vegetables were again sampled from a number of nearby farms. As previously reported, tritium was the only radionuclide measured in these foods above ambient levels, although concentrations were less than in similar samples collected during the earlier study.

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SUPPLEMENTARY RADIOLOGICAL MEASUREMENTS AT THE MAXEY FLATS RADIOACTIVE WASTE BURIAL SITE - 1976 - 1977

Richard L. Blanchard *
Daniel M. Montgomery †
Harry E. Kolde ‡
Gerald L. Gels *

September 1978

* U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs
Eastern Environmental Radiation Facility
P. O. Box 3009
Montgomery, Alabama 36109

† U.S. NUCLEAR REGULATORY COMMISSION
Region II
230 Peachtree Street, N.W.
Suite 1217
Atlanta, Georgia 30303

‡ U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Environmental Monitoring and Support Laboratory
26 West St. Clair
Cincinnati, Ohio 45268

This study was conducted while the authors were located at ORP's Radiochemistry and Nuclear Engineering Branch, Cincinnati, Ohio, now located in Montgomery, Alabama.

FOREWORD

The Office of Radiation Programs (ORP) of the Environmental Protection Agency (EPA) carries out a national program designed to evaluate population exposure to ionizing and nonionizing radiation and to prepare Federal radiation protection guidance and generally applicable environmental standards necessary to protect the environment and public health. In order to carry out this responsibility, EPA has performed field studies at nuclear facilities and sites. These field studies have required the development of means for identifying and quantifying any released radionuclides, as well as the methodology for evaluating facility discharge pathways and environmental transport.

Within ORP, radioactive waste management has been assigned a high priority, and requires participation and cooperation with several State and Federal agencies. This report is one of a series directed at a specific EPA task to establish environmental radiation protection criteria and standards for management and disposal of low-level radioactive wastes, based in part on environmental pathways and radiation exposure levels. Other reports, recommendations and State assistance projects are being developed and executed to fulfill EPA obligations in the management and disposal of all types of radioactive wastes, including high-level wastes, low-level wastes, transuranium-contaminated wastes, uranium mill tailings, naturally-occurring radioactive wastes, and wastes from decommissioned nuclear facilities.

This report discusses radiological measurements made at the Maxey Flats Radioactive Waste burial site by the Radiochemistry and Nuclear Engineering Branch, Cincinnati, Ohio (now located at the Eastern Environmental Radiation Facility in Montgomery, Alabama). The measurements were made at the request of the ORP Technology Assessment Division to support EPA's program to obtain data on the effectiveness of current land burial methods and processes, and on the environmental impact of existing commercial burial sites. The measurements also furnished technical support requested by (and obtained in cooperation with) the Kentucky Department for Human Resources.

The report also furnished supplementary data to a previously published report, "Radiological Measurement at the Maxey Flats Radioactive Waste Burial Site," (EPA-520/5-76/020), which was used as the basis of this study. Measurements performed during this latter study period provide additional information on evaporator stack effluents, lateral movement of radionuclides through the soil zone in the trench and surface drainage areas, solubility of radionuclides in test-well samples, and radioactivity in indigenous foods. The results verify the earlier conclusion that no significant public health hazard presently exists in the Maxey Flats area. However, the potential long-range impact of these contaminants is still not certain and will probably depend partly upon future custodial practices at the site.

It was not the intent of these studies to ascertain the relative significance of suggested mechanisms by which radioactivity could migrate from the burial trenches. Hydrogeological studies being conducted by the U.S. Geological Survey concurrent with further radiological measurements may provide information on this, as well as furnish data useful in predicting the future impact of the burial site on the surrounding environment. Information obtained and surveillance methodologies developed at the Maxey Flats site will be utilized in planning and conducting similar studies under consideration at other commercial burial sites.

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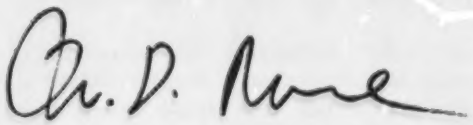
Review comments were received from the Nuclear Regulatory Commission, the Energy Research and Development Administration, the U.S. Geological Survey, several State laboratories, the Oak Ridge National Laboratory, the Kentucky Department for Human Resources, and the Nuclear Engineering Company, Inc. They were found to be very useful in the final editing of this report.

Additional comments on this report would be appreciated.They should be sent to the Director, Technology Assessment Division (ANR-459), Office of Radiation Programs, Environmental Protection Agency, 401 M Street, SW, Washington, DC 20460.



W. D. Rowe,Ph.D.
Deputy Assistant Administrator
for Radiation Programs (ANR-458)

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1. INTRODUCTION

A radiological study was conducted during 1974-1975 by the U.S. Environmental Protection Agency (USEPA) at the Maxey Flats radioactive waste burial site near Morehead, Kentucky. The objectives of this study were to:

a. Identify and measure radionuclides in the evaporator effluents discharged to the atmosphere, and determine decontamination factors of the evaporator system for the principal radionuclides.

b. Measure the radionuclide content of selected aquatic and terrestrial samples to identify potential pathways and, possibly, the critical pathways to man.

c. Measure radionuclides in selected environmental and test-well samples to support and supplement Kentucky Department for Human Resources (KDHR) measurements.

A detailed report of the EPA study with a description of the burial site and its operation was published in 1976.(1) It is assumed that the reader is familiar with this report. Copies may be obtained from the Eastern Environmental Radiation Facility (EERF), United States Environmental Protection Agency, P. O. Box 3009, Montgomery, Alabama 36109.

The 1974-1975 EPA study at Maxey Flats revealed small quantities of radionuclides outside the burial trenches in the surrounding streams that drain the site and in sediment from the test wells. Although 15 radionuclides were identified in evaporator stack effluent, only tritium was discharged at a rate of possible significance. The observed maximum discharge rate of tritium was 1.9×10^3 μCi/sec. Radiochemical analyses of well water, fresh vegetables grown near the site and milk revealed only tritium in excess of ambient levels. Consumption of these foods by the nearby population was estimated to result in radiation doses of less than 1 mrem/yr. It was concluded that the burial site did not at the time present a significant public health hazard.

Results of the study strongly indicated precipitation run-off from the site surface to be the major mechanism of transport of radioactivity from the burial site to nearby streams. However, questions regarding the future importance of other transport pathways, the mechanism by which radioactivity, particularly plutonium isotopes, migrates to the test wells that surround the trench area, and the contribution of evaporator discharges to site surface contamination remained essentially unanswered. Suggested projects for further study to provide information on these and other questions were:(1)

1. Determine the extent to which subsurface migration of radionuclides through fissure systems in the rocks and lateral migration through the soil zone contribute radioactivity to the surrounding streams. The U.S. Geological Survey (USGS) is presently studying the subsurface hydrology at the site to provide information on these pathways.(2)

2. Determine the mechanism by which radioactivity, particularly plutonium isotopes, migrates to the test wells that surround the trench area. Although plutonium is generally considered to be essentially immobile in a soil matrix, its mobility may be enhanced by a number of complex mechanisms. Brookhaven National Laboratory (BNL) is presently studying the chemical reactions that occur in the buried wastes.(3,4)

3. Determine the total quantity of radioactivity that leaves the burial site and is transported down Rock Lick Creek each year.

4. Determine the quantity of ^{14}C in evaporator stack discharges -- there are approximately 2.5×10^4 Ci of ^{14}C buried at the site (5) -- and improve the measurements of the decontamination factors (DF) determined earlier for cesium and plutonium in the evaporator.

5. Verify food chain dose estimates to the surrounding population.

6. Determine radionuclide concentrations in air outside the fence-line to verify dose estimates from evaporator effluents, and determine the contribution of washout from the plume to surface water contamination.

7. Determine present levels of environmental radioactivity to compare with those of 1974-1975 to ascertain the effects of the improved waste management practices at the burial site.

Although it was not feasible for this laboratory to investigate all items listed above, the studies that were conducted during 1976 and 1977 have produced additional information regarding evaporator effluents and radioactivity on the site:

1. Analysis of auger samples taken from the top of the Main East Wash, the principal surface-water run-off passage on the site, to obtain a profile of radionuclide concentrations with depth.

2. Analysis of auger samples obtained in the trench area to detect possible lateral migration of radioactivity through the soil zone.

3. Analysis of filtered water and sized particles from a test well to provide information regarding the physico-chemical properties of plutonium in these wells.

4. Analyses of additional milk and fresh vegetable samples from the area to determine if previously estimated food pathway dose estimates had changed.

5. Analyses of both input and effluent samples from the evaporator for radionuclides, including ^{14}C which was not measured earlier, to obtain improved measurements of the decontamination factors and estimates of the quantities discharged to the atmosphere.

Further studies are presently being conducted at the Maxey Flats site by the Eastern Environmental Radiation Facility (EERF), USEPA, and will be reported later. Information obtained in these studies should be useful in assessing the environmental impact of low-level radioactive waste burial sites and assist in setting criteria for site selection, a fundamental responsibility of the Office of Radiation Programs, USEPA.

These supplementary measurements were performed by the Radiochemistry and Nuclear Engineering Branch, Cincinnati, Ohio, with the support of the Technology Assessment Division, ORP, USEPA, and the Radiation and Product Safety Branch, KDHR. Assisting the investigators were individuals, listed in Appendix 1, from the KDHR, the U.S. Geological Survey, the U.S. Environmental Protection Agency, and the Nuclear Engineering Company.

2. ON-SITE MEASUREMENTS

Although efforts were primarily directed to the evaluation of dose to individuals in the vicinity of the burial site and determination of the critical exposure pathways, some work was initiated to provide data in support of studies to evaluate the extent or potential of subsurface movement of radioactivity from the trenches.

It is recognized that a realistic evaluation of the suitability of the site or its long term radiological impact would require extensive hydrogeological studies. Our efforts were limited to the radiochemical analyses of auger samples and the determination of radioactivity associated with various sized particles from a test-well sample. The auger samples were from site drainage pathways and the trench area. Holes were augered in the trench area at locations selected for future drilling of piezometer wells to ensure that the wells would not intercept burial trenches. These samples provided the opportunity to examine subsurface samples for evidence of lateral movement of radioactivity from the trenches. Samples from the drainage areas were taken to investigate the possible transport of radioactivity in the shallow soil zone. Since the Main East Wash was shown to be a major pathway for radioactivity leaving the site via surface-water run-off,(1) it was of interest to determine the relative importance of subsurface transport in the shallow soil zone.

Previous work showed that plutonium activity in test-well water samples was associated with particulate material.(1) If the source of plutonium in the test wells is from subsurface movement from the trenches, it is important to determine the transport mechanism. Characterization of the physico-chemical properties of plutonium in the wells will be an important contribution to the determination of the transport mechanism and, as mentioned previously, this work is in progress.(3,4) Our work was limited to determining the particle-size distribution of plutonium and to measure gamma-ray-emitting isotopes detected in a test well. Although it is recognized that these data are of limited value alone, they are presented so that they will be available to other investigators.

2.1 Auger Sampling and Analysis

Samples were obtained by USGS personnel with a 6-in-diameter power auger mounted on the back of a truck.* Prior to augering, approximately 1 m of topsoil was removed with a backhoe to prevent contamination of the holes with surface soil. Augering was performed vertically from the bottom of these holes. The maximum augering depth was approximately 5 m and was usually limited to less than 5 m because the auger bit could not penetrate a sandstone bed underlying the site at that depth. The earthen samples were collected at the bottom of the 1-m hole after auger cuttings had risen from the cutting bit along the auger stem. Samples were obtained over various depth intervals ranging from 30 to 45 cm. Although this method was rather crude with poor depth resolution, cross-contamination of samples was judged by the authors not to be significant.

The samples were oven dried to constant weight at 110° C and sieved through a No. 10 mesh screen. Four-hundred-gram samples were analyzed for gamma-ray emitting radionuclides by gamma spectroscopy with an 85-cm^3 Ge(Li) detector. Ten-gram samples were analyzed for plutonium isotopes using the radiochemical procedure previously outlined.(1)

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* All augering depths given in this report are referenced to ground level.

2.2 *Auger Samples From the Trench Area*

The locations selected for four piezometer wells are shown in Figure 2.1. Four holes were augered around two of the well sites, UB-1 and UB-2, and three holes were augered around the other sites, UB-3 and UB-4. At UB-1 and UB-2, the four holes formed the corners of squares with the proposed drilling sites at the centers. At UB-3 and UB-4, the three holes formed the corners of triangles with the proposed drilling sites at the centers.

The concentration of radionuclides detected in the samples are given in Table 2.1 The samples consisted of regolith (rock which has been weathered "in place") and alluvium. The results, in general, show only low-level contamination, primarily ^{60}Co and ^{137}Cs. Plutonium analyses of ten selected auger samples also indicated low-level plutonium contamination. The highest radionuclide concentrations were observed in UB-1-4 and UB-3-1. In UB-1-4, the concentrations were much greater at the 1.5 - 1.8 m depth interval compared to the 3 - 3.5 m interval. The radionuclide concentrations in the samples from UB-3-1 also decreased with depth, but not so dramatically. It should be noted that in all cases the radioactivity levels were quite low in regard to a public health hazard, but did indicate that contamination from some source had occurred.

These data are of limited value without additional hydrogeological information. However, the higher levels at the shallow depths suggest that surface contamination may be responsible for most of the radioactivity observed. Some of the material augered may have actually been compacted fill material used for capping the trenches. Hence, lateral migration from the trenches to these locations and depths is not significant. This is further evident from a comparison of the auger sample measurements with the quantities reported to be buried in the trenches adjacent to the augering sites and in the water removed from these trenches.(3,6) The concentration of dissolved radionuclides measured in water from two nearby trenches and the quantities estimated to have been buried in five nearby trenches are given in Table 2.2. It is recognized that the radioactivity inventory from which the latter was extracted may not be totally accurate, (6) but it is the best available data. Considering the very large quantities present in close proximity to the coring sites, the very small amounts observed in the auger samples indicate that if lateral migration of radionuclides from the trenches occurs, it is very slow. However, these observations do not preclude the possibility of subsurface migration from the trenches through fissure systems in the rocks at other locations on the site or at a greater depth than was sampled.

2.3 *Site Drainage Samples*

Auger samples were taken in the site drainage pathways to the east and south of the site at locations shown in Figure 2.2. The two locations to the east were in the Main East Wash and are designated as the North Channel and South Channel.

Surface samples were collected before removing the upper 1 m of soil with a backhoe. In the Main East Wash, auger samples were collected from depths of 1 m to 5 m. At the southern boundary of the site, inability of the auger to penetrate a sandstone bed limited the sampling depth to 0.8 m below ground level (No hole was dug with a backhoe at this site, and augering commenced at ground level).

The results of the radionuclide analyses, presented in Table 2.3, show that ^{60}Co and ^{137}Cs were the only non-naturally-occurring gamma-ray-emitters in samples down to 1 m. Plutonium isotopes were detected at depths greater than 1 m, but the concentrations were substantially lower than samples from the top 1 m. The decrease in radionuclide concentrations with depth, plus the presence of alluvial gravel, sand, and silt to depths of 1 m in the Main East Wash suggested that the radionuclides in this interval were probably associated with the sediment deposited from surface run-off or surface run-off infiltrating the shallow alluvium.

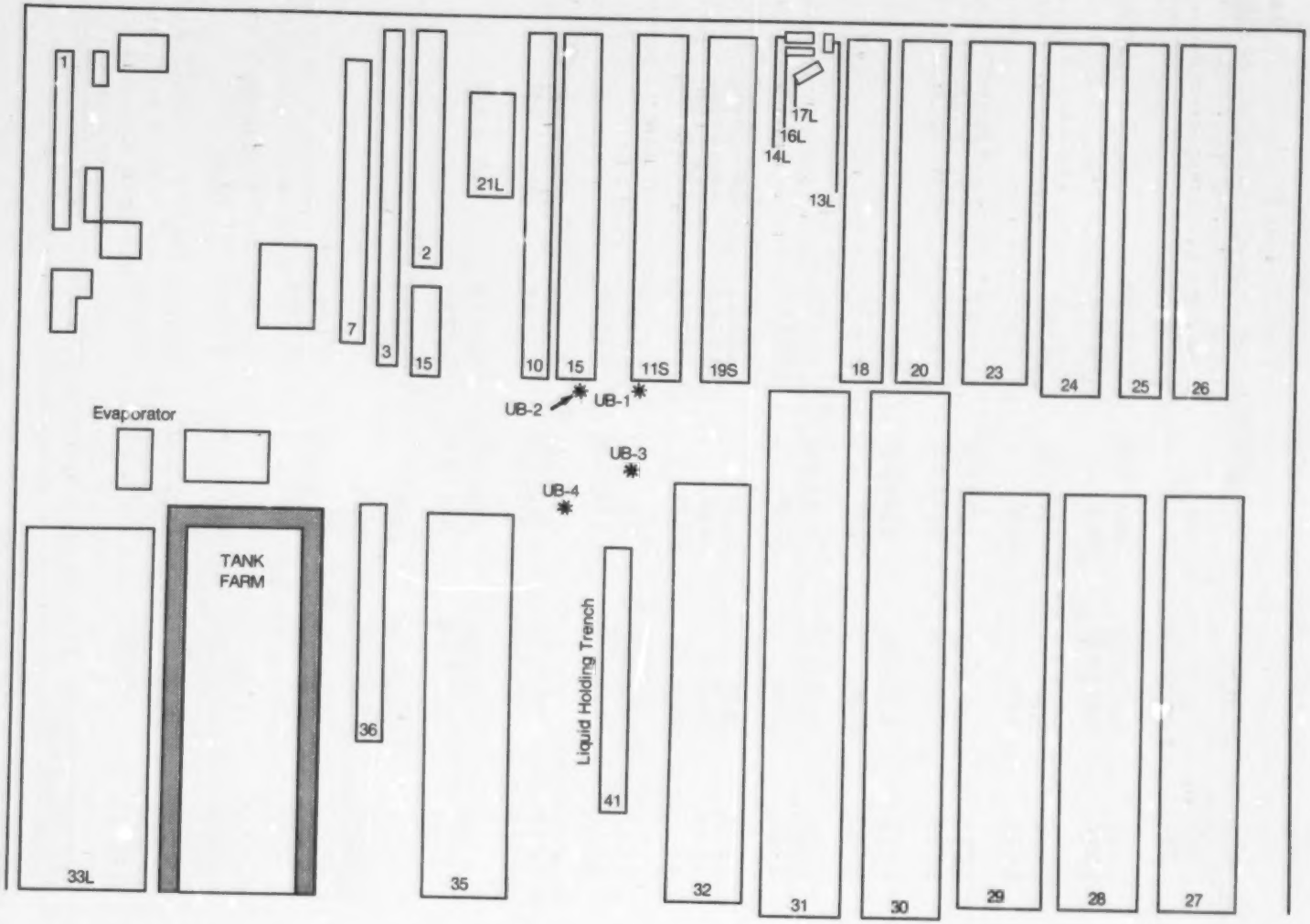

Figure 2.1. Locations of the Four Piezometer Wells on the Burial Site Around Which Auger Samples Were Taken and Analyzed for Radioactivity.

Table 2 .1

Gamma Spectral and Plutonium Analyses of Auger Samples - November 1976

(pCi/g)

Sample	Depth* (m)	^{60}Co	^{137}Cs	^{226}Ra	^{238}Pu**	^{239}Pu**
UB-1-2	1.5-1.8	0.12±0.03	0.14±0.05	2.3±0.9		
UB-1-2	3.0-3.4	0.16±0.07	<0.05	2.6±0.8		
UB-1-3	1.5-1.8	<0.06	0.11±0.04	3.1±0.6		
UB-1-3	3.0-3.5	<0.06	<0.06	1.9±1.0		
UB-1-4	1.5-1.8	1.5 ±0.1	2.27±0.06	3.8±0.2	2.6 ±0.2	0.17 ±0.02
UB-1-4	3.0-3.5	0.17±0.06	0.12±0.05	2.9±0.9	0.15 ±0.02	0.008 ±0.003
UB-2-1	1.5-1.8	0.13±0.06	0.20±0.07	3.0±1.0		
UB-2-1	2.7-3.0	<0.06	<0.06	2.5±0.8		
UB-2-2	1.5-1.8	0.04±0.02	0.12±0.02	3.0±0.3		
UB-2-2	2.7-3.0	<0.06	<0.06	3.0±1.0		
UB-2-3	1.5-1.8	<0.03	<0.03	2.6±0.2	0.008±0.002	<0.002
UB-2-3	3.0-3.4	<0.06	<0.06	3.3±0.8	0.020±0.004	0.002 ±0.001
UB-2-3	4.6	<0.06	<0.06	2.6±0.8	0.004±0.002	0.003 ±0.002
UB-2-4	1.5-1.8	0.37±0.07	0.66±0.07	2.0±0.9		
UB-2-4	2.7-3.0	0.11±0.06	0.12±0.06	1.3±0.8		
UB-3-1	1.5-1.8	3.7 ±0.1	0.14±0.07	2.2±0.9	0.14 ±0.02	0.012 ±0.003
UB-3-1	2.7-3.0	1.4 ±0.1	0.10±0.07	2.7±0.8	0.05 ±0.01	0.007 ±0.002
UB-3-2	1.5-1.8	0.25±0.06	0.22±0.05	2.6±1.0	0.05 ±0.01	0.003 ±0.002
UB-3-2	2.7-3.5	0.30±0.06	0.08±0.05	2.5±0.7		
UB-3-3	1.5-1.8	0.13±0.06	<0.04	2.4±0.4		
UB-3-3	2.9-3.0	0.10±0.06	<0.04	3.6±0.9		
UB-4-1	1.5-1.8	0.04±0.02	0.12±0.02	2.7±0.3		
UB-4-1	2.7-3.0	0.03±0.02	<0.02	2.1±0.4		
UB-4-2	1.5-1.8	0.16±0.04	0.06	2.3±0.7	0.050±0.003	0.0014±0.0005
UB-4-2	2.7-2.9	0.22±0.06	<0.06	2.7±0.9	<0.06	<0.003
UB-4-3	1.5-1.8	<0.05	<0.05	2.3±0.9		
UB-4-3	2.9-3.5	0.10±0.05	0.08±0.05	2.5±0.7		

* Depth below ground level.

** Only 10 samples were analyzed for plutonium.

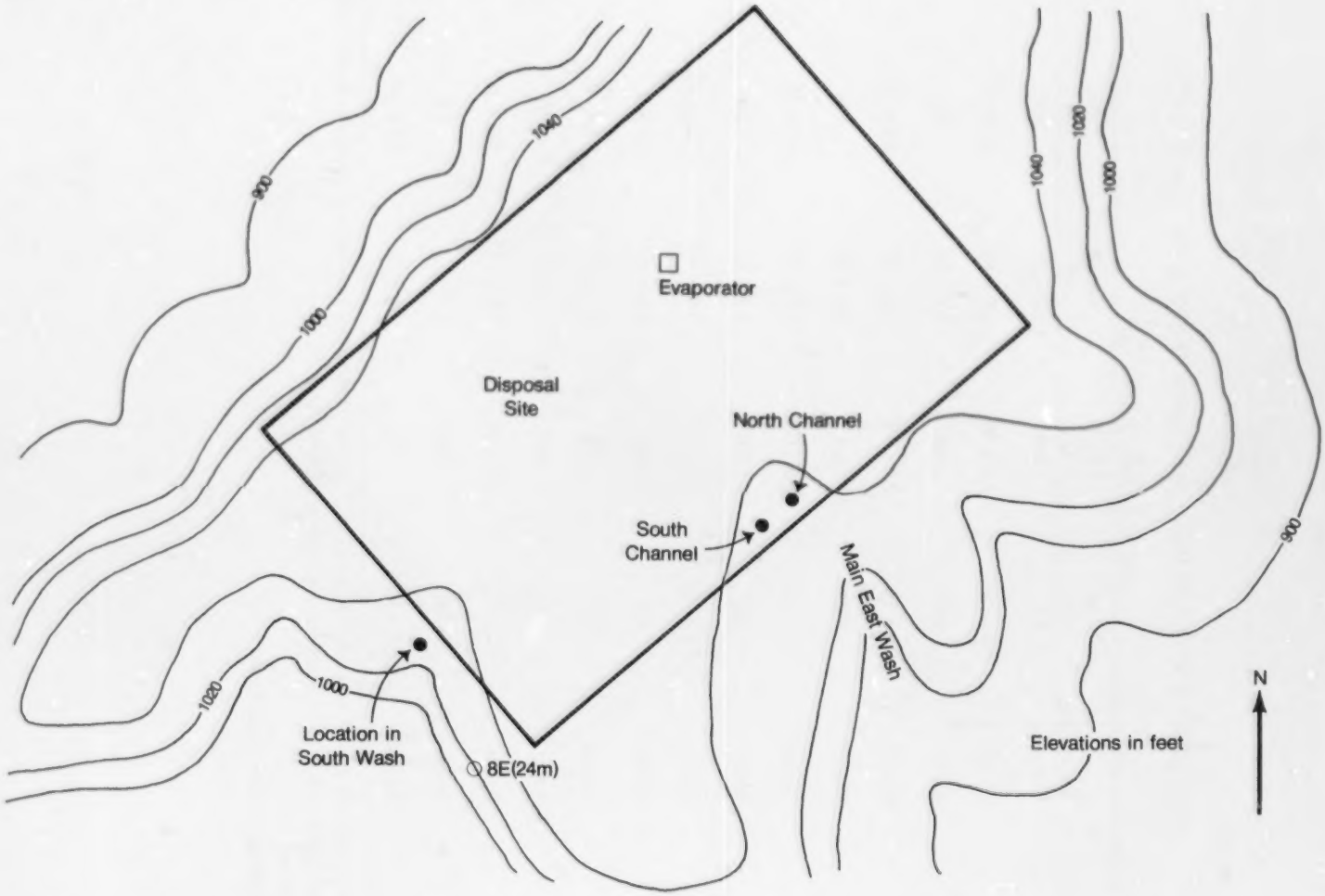

Figure 2.2. Locations of Auger Samples Taken in Site Drainage Pathways and Test Well No. 8E With Depth.

Table 2.2

Radionuclides in Trench Water (pCi/l) and Buried in the Trenches (Ci)

Near the Auger Holes (3,6)

Radionuclide	Form	Trench 11S	Trench 15	Trench 19S	Trench 32	Trench 35
^{3}H	Water	*NR*	*NR*	*6.9×10^{7}*	*NR*	*2.0×10^{9}*
	Buried	5.5×10^{3}	3.1×10^{2}	2.8×10^{3}	1.2×10^{3}	2.2×10^{2}
^{60}Co	Water	*NR*	*NR*	*1.3×10^{3}*	*NR*	*4.7×10^{2}*
	Buried	6.0×10^{-1}	2.0×10^{2}	1.5×10^{4}	3.4×10^{3}	2.8×10^{3}
^{90}Sr	Water	*NR*	*NR*	*2.6×10^{5}*	*NR*	*1.2×10^{4}*
	Buried	8.5×10^{2}	8.6×10^{1}	1.8×10^{2}	4.0×10^{1}	2.1×10^{0}
^{137}Cs	Water	*NR*	*NR*	*3.2×10^{3}*	*NR*	*$<1.0 \times 10^{2}$*
	Buried	5.7×10^{2}	2.3×10^{2}	1.2×10^{2}	2.0×10^{2}	1.8×10^{0}
^{238}Pu	Water	*NR*	*NR*	*1.7×10^{5}*	*NR*	*1.1×10^{1}*
	Buried	NR	NR	2.2×10^{-1}	1.2×10^{4}	3.7×10^{3}
^{239}Pu	Water	*NR*	*NR*	*NR*	*NR*	*NR*
	Buried	6.4×10^{1}	2.2×10^{1}	1.3×10^{2}	5.0×10^{2}	1.4×10^{2}
Pu-X	Water	*NR*	*NR*	*NR*	*NR*	*NR*
	Buried	1.6×10^{1}	NR	1.8×10^{1}	4.3×10^{2}	5.3×10^{2}

Water from trenches 19S and 35 was collected on 9/76 and 4/76, respectively. The concentrations are in pCi/l and italicized.
Radionuclides buried in the trenches are corrected for decay to June 1976.
NR - Not reported.
Pu-X - Unidentified plutonium isotopes.

Table 2.3

Radionuclide Concentrations in Auger Samples near Site Boundary, November 8, 1976 (pCi/g)

Depth*,m	^{60}Co	^{137}Cs	^{226}Ra	^{238}Pu	^{239}Pu
			Main East Wash, North Channel		
Surface	0.29 ± 0.04	0.24 ± 0.04	3.0 ± 0.6	0.30 ± 0.04	0.05 ± 0.01
1 m	0.48 ± 0.03	5.9 ± 0.1	2.7 ± 0.5	3.31 ± 0.03	0.65 ± 0.09
1.5 - 1.8	<0.03	<0.03	2.3 ± 0.3	0.010 ± 0.007	0.007 ± 0.005
3.0 - 3.3	<0.03	<0.03	1.8 ± 0.4	0.013 ± 0.003	0.003 ± 0.001
4.5 - 5.0	<0.03	<0.03	1.6 ± 0.3	<0.002	<0.002
			Main East Wash, South Channel		
Surface	0.20 ± 0.03	0.24 ± 0.03	2.2 ± 0.5	0.24 ± 0.03	0.10 ± 0.01
1 m	0.02 ± 0.01	0.03 ± 0.01	2.2 ± 0.2	0.004 ± 0.003	<0.002
1.5 - 1.8	<0.01	<0.01	2.2 ± 0.2	<0.002	<0.002
3.0 - 3.6	<0.03	<0.03	2.2 ± 0.5	<0.002	<0.002
4.5 - 5.0	<0.03	<0.03	2.2 ± 0.4	0.008 ± 0.004	<0.004
			South of Site		
Surface	1.02 ± 0.06	1.07 ± 0.05	2.4 ± 0.5	2.2 ± 0.1	0.15 ± 0.02
0.75	0.13 ± 0.02	0.44 ± 0.03	2.1 ± 0.4	3.4 ± 0.2	0.07 ± 0.02

* Depth below ground level.

The absence of ^{60}Co and ^{137}Cs and the very low plutonium concentrations at depths greater than 1 m suggest that subsurface migration of radionuclides in the shallow soil zone has not occurred at this location and depth. Since this location is approximately 30 m from the nearest trench, these data do not imply that subsurface migration has not occurred at distances closer to the trenches. However, these data strongly indicate that the source of radioactivity in the Main East Wash, the primary aqueous pathway by which radioactivity leaves the site, is surface run-off and not lateral migration in the shallow soil zone at depths to 5 m.

2.4 Test-Well Sample Particle-Size Distribution

Test-well samples were collected on June 27, 1976, for particle-size determination. The initial intent was to make particle-size determinations on samples from all wells that had previously been shown to contain radioactivity.(1) However, the process was so laborious and time consuming that available resources limited this investigation to one well sample, a 3.7 liter water sample with suspended sediments from well 8-E. The test well location with depth in meters is shown in Figure 2.2. Previous analyses had shown that samples from this test well contained the highest plutonium concentration of all wells sampled.

The fractionation and harvesting of particles from the test-well water sample were accomplished using a sedimentation method and by wet sieving of the sediment particles.(7) Particles with diameters greater than 53 μm were first collected by wet sieving using a 270-mesh screen. The sedimentation procedure that followed involved repeated gravitational settling and decantation to a fixed depth in a large graduated cylinder until a good separation was achieved. The rate of settling of the particles was assumed to be governed by Stoke's Law which is applicable for particles of nearly spherical shape. The fall velocity for particles with a density of 2.65 g/cm^3 is given by:

$$V = \frac{0.8983}{\mu} d^2, \qquad (2.1)$$

where V is the velocity in cm/sec, d is the particle diameter in mm, and μ is the dynamic viscosity of the fluid in poise (μ = 0.009358 for water at 23° C).

Initially a gross separation was made by allowing 3.7 liters of the water-sediment mixture to settle for 3 days to remove most particles from the water. Since some smaller particles (assumed to be less than 2 μm) do not settle, the decanted liquid was filtered through 0.45 μm membrane filters. These filters were saved to be included with the 0.45-5 μm fraction. The filtrate was then evaporated to 400 ml for radiochemical analysis.

The particulate material was wet sieved through a 270-mesh screen to collect all particles with diameters greater than 53 μm. Distilled water was used for wet sieving and for all subsequent steps in the settling procedure when additional water was needed.

The material which had passed through the sieve (< 53 μm diameter) was placed in the settling cylinder (See Figure 2.3) to separate the smaller particle size groups: 0.45 - 5 μm, 5 - 20 μm and 20 - 53 μm. The settling cylinder was a 500-cc graduated cylinder with the top cut off just below the pouring lip so that a rubber stopper could be inserted for shaking the solution to suspend the particles. A glass siphon was used with a peristaltic (sigmamotor) pump as shown in Figure 2.3. After shaking the sample to suspend all particles and the appropriate settling time was achieved, the liquid containing the desired sized particles was removed by pumping into the receiving vessel.

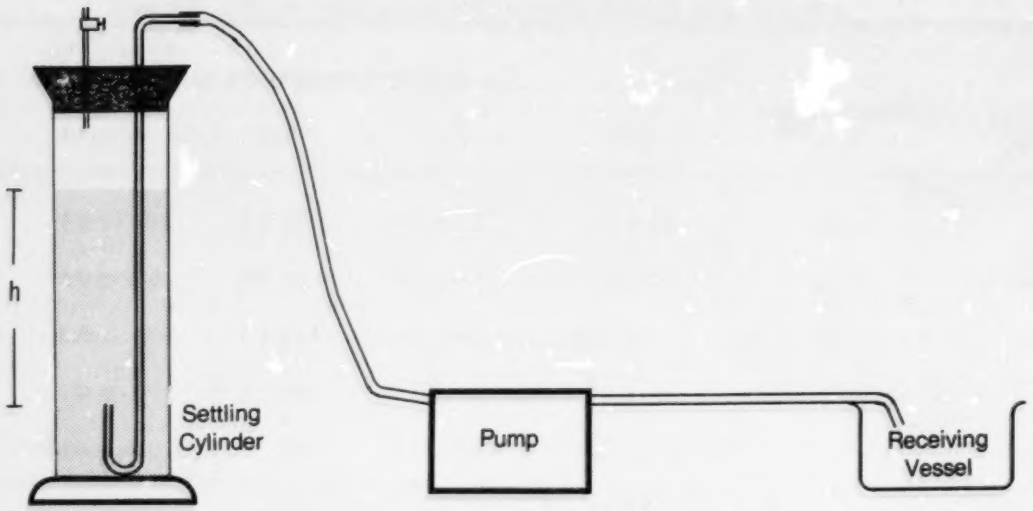

Figure 2.3. Sedimentation Apparatus.

The particles in the smallest diameter range (0.45 - 5 μm) were separated first. The time required for 5-μm particles to settle the distance h was obtained using the fall velocity computed by Equation 2.1. After suspending the particles in the cylinder and the fall time had elapsed, the liquid in the cylinder was pumped to the receiving vessel. This liquid represents a sample from which all particles greater than 5 μm have been removed. The liquid collected in the receiving vessel was then filtered through 0.45 μm filters to collect particles in the 0.45 - 5 μm range. The filtrate was returned to the settling cylinder and the process repeated until the yield of particulate material, determined by weighing the filters, was negligible. This process was repeated for the other particle-size groups with appropriate settling times for the specific particle diameters.

The filters from the various particle-size groups were composited for analysis. The analyses included gamma-ray spectroscopy and plutonium separations. The results, presented in Table 2.4, show the presence of ^{60}Co, ^{137}Cs, ^{238}Pu, ^{239}Pu, and naturally-occurring ^{226}Ra.

The radioactivity was primarily associated with the particulate material, as indicated by the absence of detectable quantities of ^{60}Co and ^{137}Cs and the very low concentrations of plutonium in the filtrate. (Particles with diameters less than 0.45 μm are considered to be in solution.) The highest radionuclide concentrations were found in the 0.45 - 5 μm particle-size range. This may be indicative of the higher ion-exchange capacity of the smaller particles (this is commonly observed with ions associated with sediment). However, this conclusion cannot be confirmed in this case because neither ion-exchange capacity measurements nor chemical species analysis were performed.

Radionuclides were measured in water from trench No. 37 in April 1976.(3) This trench, approximately 100 m from test well 8E, is the nearest one for which data on dissolved radionuclide concentrations are available. In Table 2.5 are listed the soluble radionuclide concentrations measured in the water from trench No. 37 and in the June 1976 test-well sample. A direct comparison is difficult because the actual source of radionuclides found in the test well has not been established and essentially all of the radionuclides, except ^{3}H, were associated with particulate matter. However, it is apparent that if the radionuclides observed in test-well samples originated in the trenches, considerable dilution occurs during their movement to the test wells.

Table 2.4

Particle-Size Distribution of Radionuclides in Test Well-8E

Particle size (microns)	Concentration (g/l)	Radionuclide Concentration, pCi/g (dry weight)				
		^{60}Co	^{137}Cs	^{226}Ra	^{238}Pu	^{239}Pu
0.45 - 5	0.29	3.8 ± 0.4	2.2 ± 0.4	30 ± 8	14.9 ± 0.9	0.23 ± 0.05
5 - 20	0.96	0.7 ± 0.1	1.7 ± 0.2	20 ± 6	9.0 ± 0.5	0.20 ± 0.03
20 - 53	1.05	1.1 ± 0.03	0.8 ± 0.4	12 ± 3	5.7 ± 0.8	0.16 ± 0.02
> 53	0.23	2 ± 1	2 ± 1	<40	9.3 ± 0.1	0.14 ± 0.05
Filtrate*		<0.8	<0.8	<20	0.04 ± 0.02	<0.008

*Radionuclide concentration of filtrate is pCi/l.

± values are 2σ uncertainties based on counting error.

Table 2.5

Radionuclides in Water from Trench No. 37 and Water and Sediment from Test Well 8E

(pCi/l)

Radionuclide	Trench No. 37 (3)	Test Well 8E	
		Filtrate	Sediment
^{3}H	1.1×10^{7}	3.5×10^{2}	NA
^{60}Co	5.0×10^{4}	$<8 \times 10^{-1}$	3.4×10^{0}
^{90}Sr	1.9×10^{3}	NA	NA
^{134}Cs	1.7×10^{3}	ND	ND
^{137}Cs	9.8×10^{3}	$<8 \times 10^{-1}$	3.6×10^{0}
^{238}Pu	1.8×10^{4}	4×10^{-2}	2.1×10^{1}

The trench water sample was collected in April 1976 and measured for dissolved radionuclides. Except for ^{3}H, all detectable radioactivity in the test-well sample was associated with sediments; not in solution.

NA Not analyzed.

ND Not detected.

3. ENVIRONMENTAL MEASUREMENTS

The purposes of additional environmental measurements were to provide data for assessing the dose to individuals from food pathways and to determine if radionuclide levels are increasing or decreasing. Measurements were limited to tomatoes from local gardens and milk from local dairies.* The drinking water pathway for individuals near the site, shown earlier to be an important pathway, was not investigated since it is routinely evaluated by the KDHR.(1)

3.1 Sampling and Analysis

Tomato samples were collected at 5 locations near the site on August 9, 1976, and September 1, 1976. The sampling locations are shown in Figure 3.1 and listed in Table 3.1. In addition, tomatoes from Aberdeen, Ohio, were collected for background. Aberdeen is approximately 48 km north of the site and would not be affected by the Maxey Flats operations or any other nuclear facility.

Radiochemical analyses were performed for ^{3}H as HTO, ^{14}C and gamma-ray emitters. Sample preparation and radioassay procedures were the same as previously reported.(1) Carbon-14 analyses were performed on three samples collected August 9, 1976. The procedure for ^{14}C involved combustion of the freeze-dried residue to CO_2, conversion of CO_2 to benzene, and liquid scintillation counting.

Milk samples were collected during three periods: June 30 - July 1, 1976, August 9 - 10, 1976, and September 1 - 2, 1976. In addition to the locations sampled during the 1974 - 1975 study, another commercial dairy farm near the site (Location 54) and a background location were included. The dairy at location 54 is approximately 1.2 km south of the site. In contrast to the other milk sampling locations, this one does not receive run-off from the burial site via Rock Lick Creek. The main source of drinking water for the cows here is a shallow farm pond which is recharged primarily from nearby surface-water run-off. The background location (BG) was a commercial dairy approximately 30 km north of the site. Cows' drinking water was also collected at some sampling locations for ^{3}H analysis.

Milk samples were analyzed for ^{3}H, ^{90}Sr, and gamma-ray emitters. Two milk samples were also analyzed for ^{14}C by benzene synthesis of the milk solids and liquid scintillation counting. The radiochemical procedures for the analyses of milk are given in the 1974 - 1975 report.(1)

3.2 Radionuclides in Tomatoes

Radionuclide concentrations measured in tomatoes are given in Table 3.2. Tritium was the only radionuclide attributed to releases from the disposal site and, considering that the site locations are isolated from site drainage, the evaporator is the source. Carbon-14 concentrations were consistent with background levels.(9) The highest ^{3}H concentration was 6.5×10^{3} pCi/kg at location 41 on August 9, 1976. Tomatoes from this location also contained the highest ^{3}H levels during 1975. The range of concentrations in tomatoes at the various sites were not significantly different from those observed the previous year (See Table 3.3). Some variability is expected as a result of differences in the quantity of ^{3}H released and climatic conditions.

These results confirm the earlier observation that the potential radiation exposure to individuals consuming vegetables from gardens near the burial site is very small.(1) The potential maximum whole body dose was computed to be about 0.01 mrem/yr.

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* Cucumbers were observed earlier to contain about twice the ^{3}H concentration as tomatoes, 7.9×10^{4} pCi/kg and 3.2×10^{4} pCi/kg, respectively.(1) However, since it is estimated that the average adult consumes 40 g/d of tomatoes and only 3.5 g/d of cucumbers,(8) tomatoes will be the principal vegetable in the food pathway. The availability of samples was also greater for tomatoes.

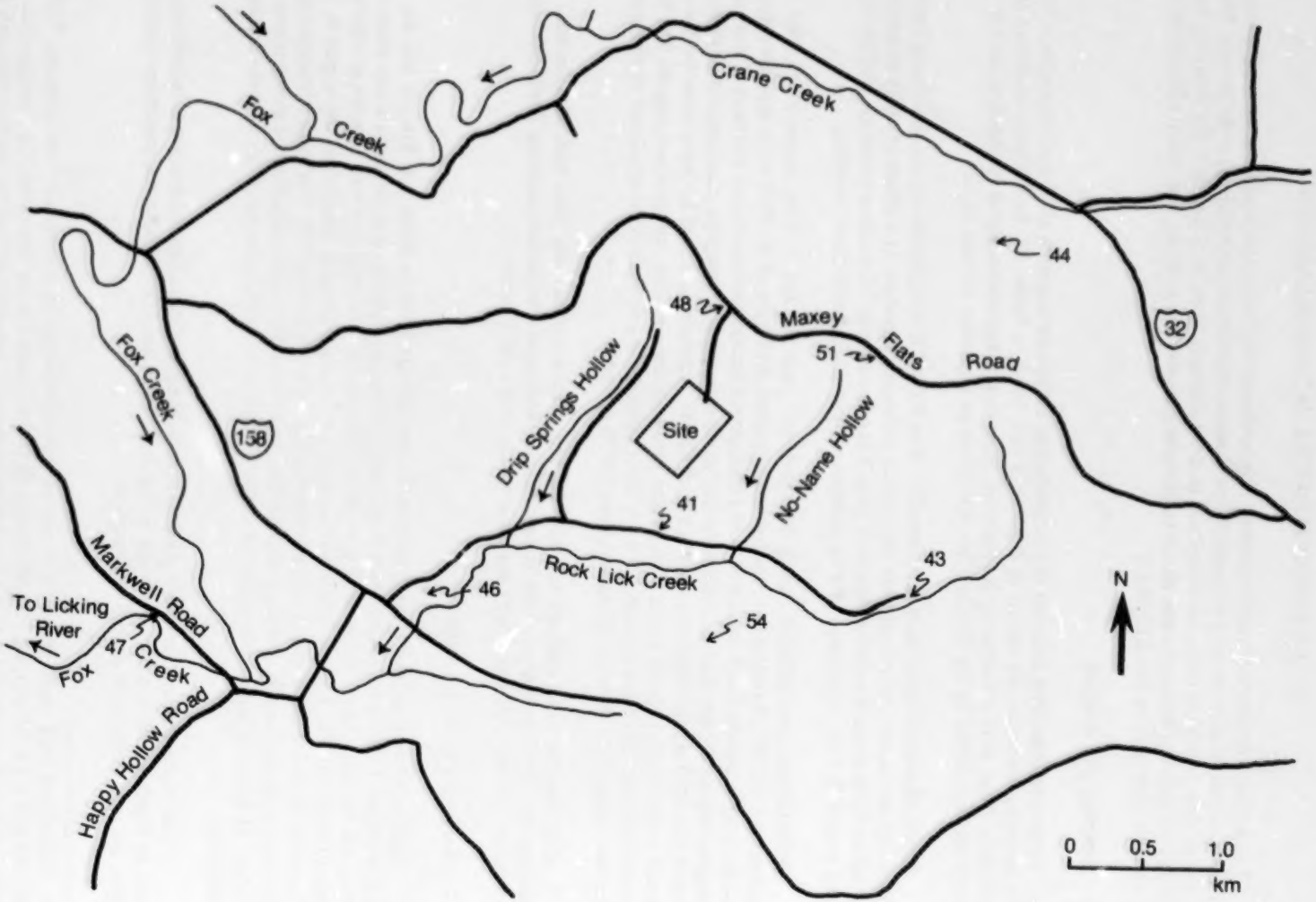

Figure 3.1. Milk and Vegetable Sampling Locations.

Table 3.1

Sampling Locations near Maxey Flats Burial Site

Site number	Location
41	Residence on Rock Lick Creek Road, approximately 1.7 km west of Rt. 158.
43	Residence on Rock Lick Creek Road, approximately 3.2 km west of Rt. 158.
44	Residence approximately 2.2 km north-northeast of site and approximately 0.3 km south of Rt. 32.
46	Dairy farm on Rock Lick Creek Road, approximately 0.3 km east of Rt. 158.
47	Dairy farm on Markwell Road, approximately 3.1 km south-southwest of the site.
48	Residence southwest of the intersection of the site access road with Maxey Flats Road.
51	Residence on Maxey Flats Road, approximately 1.1 km east of the site access road.
54	Dairy farm on Randall Hill Road, approximately 1.2 km south of site.

Table 3.2

Radionuclide Concentration in Tomatoes

Sampling Date	Location (Table 3.1)	^{3}H pCi/l (tissue water)	^{3}H pCi/kg (fresh weight)	^{14}C dpm/g C	Gamma-Ray Emitters pCi/kg (fresh weight)
8/9/76	41	2.4 ± 0.3(3)	2.2 ± 0.3(3)	NA	ND
8/9/76	43	0.7 ± 0.3(3)	0.7 ± 0.3(3)	NA	ND
8/9/76	44	1.3 ± 0.2(3)	1.2 ± 0.2(3)	NA	ND
8/9/76	48	6.9 ± 0.2(3)	6.5 ± 0.2(3)	18.2 ± 0.6	ND
8/9/76	51	2.4 ± 0.2(3)	2.3 ± 0.2(3)	19.5 ± 0.8	ND
8/9/76	AB	<0.2(3)	<0.2(3)	19.0 ± 0.8	ND
9/1/76	41	3.7 ± 0.2(3)	3.4 ± 0.2(3)	NA	ND
9/1/76	43	0.6 ± 0.3(3)	0.6 ± 0.3(3)	NA	ND
9/1/76	44	1.1 ± 0.2(3)	1.0 ± 0.2(3)	NA	ND
9/1/76	48	4.5 ± 0.3(3)	4.3 ± 0.3(3)	NA	ND
9/1/76	51	2.0 ± 0.4(3)	1.9 ± 0.4(3)	NA	ND
9/1/76	AB	<0.2(3)	<0.2(3)	NA	ND

AB Background location at Aberdeen, Ohio.
NA Not analyzed.
ND Not detected; typical detection limits were ^{60}Co - 8 pCi/kg, ^{137}Cs - 8 pCi/kg.
± Values are 2σ uncertainties based on counting error.
Exponents of 10 are indicated by numbers in parentheses.

Table 3.3

A Comparison of the 1975 and 1976 Average Tritium Concentrations in Tomatoes and Milk

Location No.	1975	1976
	Tomatoes, pCi/kg (fresh weight)	
41	4.0 (3)	2.8 (3)
44	1.0 (3)	1.1 (3)
48	5.3 (3)	5.4 (3)
51	1.8 (3)	2.1 (3)
	Milk, pCi/l	
41	6.5 (3)	2.5 (3)
46	2.6 (3)	1.7 (3)
47	1.3 (3)	5.0 (2)

Exponents of 10 are indicated by numbers in parentheses.

3.3 Radionuclides in Milk

The results of the milk analyses are presented in Table 3.4. Tritium is the only radionuclide in the samples taken near the site (Locations 41, 46, 47, and 54) which can be unambiguously attributed to releases from the disposal site. The highest concentration observed during this reporting period was 3.6×10^3 pCi/l at Location 41 on August 7, 1976, compared to 6.5×10^3 pCi/l at the same location on August 27, 1975. An additional sampling station (Location 54) showed ^3H contamination which was somewhat lower than the levels observed in milk from cows receiving their water from Rock Lick Creek. The source of ^3H ingested by cows at Location 54 is from atmospheric releases rather than aqueous releases. Since the ^3H levels in the cows' drinking water is similar to the milk, the most likely pathway for ^3H at Location 54 is from the deposition of ^3H discharged from the evaporator stack to the pond. For cows pastured along Rock Lick Creek (Locations 41, 46, and 47), the principal source of ^3H in the creek is surface-water run-off from the burial site, which is partly or completely due to site-surface contamination. The tritium concentrations in milk from cows pastured along Rock Lick Creek in 1976 are about one-half those observed in milk at the same locations during the 1974 - 1975 study (See Table 3.3). This reduction may be due to better operating procedures implemented at the burial site which have resulted in less ground surface contamination.

The ^{90}Sr levels in milk varied from 3 to 7 pCi/l. Although the concentrations in milk produced near the burial site ranged above those in the background samples, they were not significantly higher and could not be distinguished from atmospheric fallout from weapons testing. No gamma-ray emitters, aside from naturally-occurring ^{40}K, were detected in any milk samples. The ^{137}Cs concentrations were below the minimum detectable level, 8 pCi/l.

The ^{14}C levels in milk were 18 and 19.8 dpm/g carbon at Locations 41 and 46, respectively. These levels are consistent with ambient levels of ^{14}C throughout the country, 15-20 dpm/g carbon.(9)

The dose associated with the ingestion of ^{3}H in milk was estimated from the concentrations measured at Location 41. These data were used because the highest ^{3}H concentrations occurred here, and the milk is consumed by the residents. The average ^{3}H concentration of milk for three sampling dates was 2.5×10^{3} pCi/l. Assuming a daily intake of 1 liter and a dose conversion factor of 6.2×10^{-5} (mrem/yr)÷(pCi/day), the associated whole body dose to an adult was 0.2 mrem/year.

Table 3.4

Radionuclides in Milk and Cow's Drinking Water

(pCi/l)

Date	Location	^{3}H	^{14}C*	^{90}Sr
		Milk		
6/30/76	41	2.3 ± 0.2 (3)	NA	5 ± 2
7/01/76	46	1.9 ± 0.2 (3)	NA	7 ± 2
7/01/76	47	0.6 ± 0.1 (3)	NA	3 ± 1
7/01/76	54	1.3 ± 0.2 (3)	NA	5 ± 2
7/01/76	MH	0.4 ± 0.1 (3)	NA	3 ± 1
8/09/76	41	3.6 ± 0.2 (3)	NA	NA
8/10/76	46	1.6 ± 0.2 (3)	NA	5 ± 1
8/10/76	47	0.4 ± 0.1 (3)	NA	6 ± 1
8/09/76	54	0.5 ± 0.1 (3)	NA	7 ± 2
8/09/76	MH	0.2 ± 0.1 (3)	NA	4 ± 1
8/09/76	CIN	<0.2 (3)	NA	NA
9/01/76	41	1.6 ± 0.1 (3)	18.0 ± 0.6	6 ± 2
9/02/76	46	1.6 ± 0.1 (3)	19.8 ± 0.6	5 ± 1
9/01/76	47	0.5 ± 0.1 (3)	NA	2 ± 1
9/02/76	54	0.7 ± 0.1 (3)	NA	6 ± 2
9/02/76	BG	<0.2 (3)	NA	3 ± 1
		Cow's Drinking Water		
6/30/76	46	3.3 ± 0.2 (3)	NA	NA
7/01/76	54	1.6 ± 0.2 (3)	NA	NA
8/09/76	46	2.7 ± 0.2 (3)	NA	NA
8/09/76	54	1.0 ± 0.2 (3)	NA	NA
9/01/76	46	2.6 ± 0.2 (3)	NA	NA
9/01/76	54	1.0 ± 0.2 (3)	NA	NA

* ^{14}C concentration is dpm/gram stable carbon.

± Values are 2-σ uncertainties based on counting error.

MH Morehead Dairy; CIN - Cincinnati dairy; BG - background location.

NA Not analyzed.

Exponents of 10 are indicated by numbers in parentheses.

4. EVAPORATOR STUDY

4.1 Introduction

During the period of this report, two series of tests were performed to supplement previous studies of airborne radioactivity discharges from the evaporation of trench leachate. Tests nos. 18, 19, and 20 were conducted on September 1 and 2, 1976, and tests nos. 21 and 22 on May 18 and 19, 1977. Table 4.1 provides details of sampling periods, sample volumes and composition of the leachate being evaporated.

Since the previous report,(1) evaporator operation has been modified. Trench leachate awaiting processing is now stored in 10 large holding tanks that are housed in an aluminum building with an excavated earthen floor. Of greatest significance, operation of the evaporator was reduced from a 24-hour to an 8-hour per day, 5-day per week schedule on August 30, 1976. This, of course, lessens the amount of radioactivity discharged to the atmosphere as well as the radiation dose contribution to the surrounding population that was calculated on an annual basis in the previous report.(1)

4.2 Sample Collection

The stack effluent sampling system remained similar to that used in the previous tests.(1) During tests nos. 21 and 22, however, a gas collection bottle was inserted momentarily after the air filter to withdraw grab samples of effluent gas. Before entering the 1.75-liter evacuated metal bottle, the gas passed through a silica gel bed to remove residual moisture. Sampling required less than one minute, at the times indicated in Table 4.1.

Nine of the leachate holding tanks (tank E was empty at the time) were sampled on May 19, 1977, to determine ^{14}C concentration levels. The samples consisted of 250-ml aliquots obtained at the midpoint of the leachate level in the tanks. These measurements provided the first data on ^{14}C contents in trench leachate at Maxey Flats.

Table 4.1

Evaporator Stack Effluent Sampling Data

Test No.	Date	Period (hrs.)	Sampling Duration (min.)	Evaporator feed (amount, %)	Sample volumes air (m^3)	Sample volumes water (liters)
18	9/01/76	0921-1121	120	Tank J(50)*	2.52	2.88
19	9/01/76	1318-1519	120	Tank J(50)*	2.52	2.66
20	9/02/76	0924-1125	120	Tank J(50)*	2.52	2.85
21	5/18/77	1418-1555**	90	Tanks A(15), F(85)	1.93	1.94
22	5/19/77	0935-1123**	104	Tanks A(15), F(85)	2.14	2.18

* Remaining 50 percent of feed consisted of dilution water.

** Samples obtained for ^{14}C gas analysis were obtained at 1438 and 1511 hrs. during Test 21 and at 1030 and 1122 hrs. during Test 22.

4.3 Radionuclide Analysis

Water collected from stack effluent was subsequently passed through 0.45-μm membrane filters. Radionuclides present in the filtered water or on the membrane and glass fiber air filters were measured by gamma-ray spectrometry using Ge(Li) detectors or specific radiochemical techniques, as described in the previous report.(1)

Carbon-14 in the stack effluent was analyzed by placing the sample fractions in a closed distillation apparatus along with an oxidizing agent and acid.(10) Air was bubbled slowly through the sample and heat was applied to transfer CO_2 into a flask containing a basic $CaCl_2$ solution. The collected $CaCO_3$ was centrifuged, washed, weighed, and placed on a toluene solution for analysis by liquid scintillation counting.

Carbon-14 as CO_2 or other gaseous forms (CH_4, CO, etc.) was determined by mixing an aliquot of the sampled gas with relatively pure CO_2 and CH_4 carrier gases. The mixture was passed through a train consisting of a bubbler containing $Ba(OH)_2$ to collect $^{14}CO_2$, a palladium sponge catalyst heated to 550 ° C for oxidation of other carbon gases, and a second bubbler containing $Ba(OH)_2$.(11) The ^{14}C activity of the $BaCO_3$ produced in the bubblers was measured by liquid scintillation counting.

4.4 Results and Discussion

4.4.1 Carbon-14 concentrations in leachate holding tanks. Concentrations of ^{14}C in the holding tanks as of May 19, 1977, are given in Table 4.2. Concentrations vary from approximately 4×10^{-6} to 8×10^{-5} μCi/ml of leachate. (The relative amounts of ^{14}C in soluble or insoluble forms were not determined at this time). Assuming that each of the tanks contained the same amount of liquid, the overall average ^{14}C concentration was, at this time, 1.9×10^{-5} μCi/ml.

Table 4.2

Concentrations of ^{14}C in Samples of Trench Leachate From Various Tanks, as of May 19, 1977

Holding Tank	μCi/ml Concentration
A	$8.3 \pm 0.1 \times 10^{-6}$
B	$3.9 \pm 0.1 \times 10^{-6}$
C	$6.6 \pm 0.1 \times 10^{-6}$
D	$4.8 \pm 0.02 \times 10^{-5}$
E	Tank empty
F	$4.3 \pm 0.1 \times 10^{-6}$
G	$7.8 \pm 0.03 \times 10^{-5}$
H	$4.2 \pm 0.1 \times 10^{-6}$
I	$4.6 \pm 0.1 \times 10^{-6}$
J	$1.7 \pm 0.02 \times 10^{-5}$

4.4.2 Radionuclide concentrations in evaporator stack effluent and discharge rates. As before, ^{3}H, ^{60}Co and ^{137}Cs were observed in samples from each of the five tests, as indicated in Tables 4.3 and 4.4. Tritium was again the predominant radionuclide in terms of relative concentration, ranging up to 2.2 μCi/ml. Strontium-90 was observed in all sample sets analyzed, as was plutonium. Cobalt-58 was observed in stack effluent for the first time (tests 18 and 19).

Effluent samples from tests 18 to 21 were analyzed for ^{14}C since no data on its discharge were available. The radionuclide was present in every sample fraction analyzed, and at highest concentration in the dissolved solids of the filtered water samples.

Gaseous ^{14}C was observed in only one of the four gas samples obtained in May 1977, as shown in Table 4.5. It was present only in the form of CO_2 and at an amount slightly above the minimum detectable level.

Radionuclide discharge rates from the evaporator stack during the five recent tests, calculated as described in the previous report,(1) are presented in Table 4.6. As observed previously, most effluent radioactivity was contributed by ^{3}H and at many magnitudes above that of any other radionuclide.

4.4.3 Decontamination factors of the evaporator. During the effluent measurements, samples of leachate entering the evaporator system were obtained to determine plant decontamination factors (DF's) for ^{14}C, ^{60}Co, ^{137}Cs, ^{238}Pu and ^{239}Pu. DF's indicate the effectiveness of the entire treatment system in removing radionuclides, other than ^{3}H, from the waste liquid before discharge to the atmosphere. DF values were calculated by the method described in Section 2.6.6 of the previous report.(1)

For test no. 20, leachate from tank J was sampled at the point where the liquid enters the first settling tank at 1355 hours, September 1, 1976. (This liquid was held overnight in the settling tank for processing the following morning.) A sample of the water used for dilution of the leachate was obtained at the same point at 1335 hours, September 1, 1976. For test no. 21, a sample of tank A input was collected at 1300 hours, May 19, 1977, and of tank F, which was being mixed with tank A leachate, at 0937 hours on the same date. It should be noted that data from the latter two input samples are being applied to effluent measurements from test no. 21, which occurred on the afternoon of May 18.

Concentrations of ^{14}C, ^{60}Co, ^{137}Cs, ^{238}Pu and ^{239}Pu found in the input samples are given in Table 4.7. Carbon-14 in the suspended solids fraction of two sample sets was not measurable since the membrane filters were used previously for other analyses. Plutonium analyses were not performed on samples from tanks A and F.

DF's derived from these data are listed in Table 4.8. The values vary for the different tests, and are in general lower than those reported in the previous report.(1) This variation reflects the complexity of the total treatment system. The measured DF values may be influenced by the chemical composition of the incoming leachate which affects the flocculating process, the resuspension and settling time of the floc, and residual radioactivity that remains in the system, particularly in the settling tanks, from previous processed batches. The DF value determined for ^{238}Pu is more precise than that for ^{239}Pu, since the concentrations of the latter in the effluent sample fractions (see Table 4.3) were determined near or below minimum detectable levels. The average DF for plutonium given by four previous measurements was 5×10^{5}.(1)

The radiation dose to the limiting receptor* (0.8 km NNE of the evaporator) due to the atmospheric discharge of ^{14}C from the evaporator is estimated to be 1×10^{-4} mrem/yr to the lung (insoluble) and 2×10^{-7} mrem/yr to the GI tract (soluble). (This computation is described in Appendix B.) Since nearly all of the ^{14}C in the effluent was in soluble form, the latter dose is the more applicable, although both are insignificant. Tritium remains the critical radionuclide. However, since the operation has been reduced to a 40 hr per week schedule, the dose from ^{3}H to the limiting receptor has been decreased to about 0.8 mrem/yr.(1) The dose rate from all other measured radionuclides was less than 0.1 mrem/yr.

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* The limiting receptor is defined as that person(s) who resides near the site and is most likely to receive the highest dose from operations of the facility.

Table 4.3

Radionuclide Concentrations in Evaporator Stack Effluent,

Tests 18-20, μCi/ml of Air or Water

Radionuclide	Sample Type*	Test No. 18	Test No. 19	Test No. 20
^{3}H	W	$8.42 \pm 0.01 \times 10^{-2}$	$6.77 \pm 0.01 \times 10^{-2}$	$6.62 \pm 0.01 \times 10^{-2}$
^{14}C	A	$1.7 \pm 0.2 \times 10^{-12}$	NA	$2.2 \pm 0.2 \times 10^{-12}$
	W	$1.3 \pm 0.2 \times 10^{-7}$	$3.0 \pm 0.3 \times 10^{-7}$	$1.0 \pm 0.2 \times 10^{-7}$
	F	$2.3 \pm 0.3 \times 10^{-9}$	NA	$1.2 \pm 0.3 \times 10^{-9}$
^{58}Co	A	$7 \pm 2 \times 10^{-13}$	$2.7 \pm 0.5 \times 10^{-12}$	ND
	W	ND	$5 \pm 2 \times 10^{-8}$	ND
	F	ND	$1.1 \pm 0.4 \times 10^{-9}$	ND
^{60}Co	A	$3.3 \pm 0.9 \times 10^{-12}$	$6.6 \pm 0.8 \times 10^{-12}$	$2.4 \pm 0.6 \times 10^{-12}$
	W	$3 \pm 1 \times 10^{-8}$	$1.1 \pm 0.2 \times 10^{-7}$	$4 \pm 1 \times 10^{-8}$
	F	$2 \pm 1 \times 10^{-9}$	$3.0 \pm 0.6 \times 10^{-9}$	$1.9 \pm 0.4 \times 10^{-9}$
^{90}Sr	A	$1.9 \pm 0.4 \times 10^{-12}$	$2.4 \pm 0.3 \times 10^{-12}$	$1.3 \pm 0.3 \times 10^{-12}$
	W	$5.3 \pm 0.3 \times 10^{-8}$	$8.8 \pm 0.4 \times 10^{-8}$	$5.4 \pm 0.3 \times 10^{-8}$
	F	$7.0 \pm 0.5 \times 10^{-9}$	$7 \pm 4 \times 10^{-10}$	$2.2 \pm 0.4 \times 10^{-9}$
^{134}Cs	A	$1.9 \pm 0.5 \times 10^{-12}$	$4.0 \pm 0.7 \times 10^{-12}$	$2.6 \pm 0.5 \times 10^{-12}$
	W	$2 \pm 1 \times 10^{-8}$	$1.5 \pm 0.2 \times 10^{-7}$	$2 \pm 1 \times 10^{-8}$
	F	ND	ND	ND
^{137}Cs	A	$1.7 \pm 0.1 \times 10^{-11}$	$3.1 \pm 0.1 \times 10^{-11}$	$2.0 \pm 0.1 \times 10^{-11}$
	W	$1.1 \pm 0.1 \times 10^{-7}$	$7.9 \pm 0.3 \times 10^{-7}$	$1.4 \pm 0.2 \times 10^{-7}$
	F	ND	$6 \pm 3 \times 10^{-10}$	$1.1 \pm 0.3 \times 10^{-9}$
^{238}Pu	A	$3.3 \pm 0.5 \times 10^{-13}$	$2.6 \pm 0.2 \times 10^{-12}$	$2.9 \pm 0.7 \times 10^{-13}$
	W	$1.7 \pm 0.2 \times 10^{-9}$	$2.0 \pm 0.1 \times 10^{-8}$	$4.5 \pm 0.4 \times 10^{-9}$
	F	$6.2 \pm 0.4 \times 10^{-10}$	$1.6 \pm 0.1 \times 10^{-8}$	$1.1 \pm 0.1 \times 10^{-9}$
^{239}Pu	A	ND	$5 \pm 2 \times 10^{-14}$	ND
	W	ND	$3.2 \pm 0.9 \times 10^{-10}$	$5 \pm 3 \times 10^{-11}$
	F	ND	$1.7 \pm 0.3 \times 10^{-10}$	ND

* Sample types: A - air filter; W - water passed through 0.45-μm membrane filters; F - 0.45-μm filters through which water sample was passed.

± Values indicate analytical error at 2-σ confidence level.

ND Not detectable.

NA Not analyzed.

Table 4.4

Radionuclide Concentrations in Evaporator Stack Effluent, Tests 21 and 22, μCi/ml of Air or Water

Radionuclide	Sample Type*	Test No. 21	Test No. 22
^{3}H	W	1.14 ± 0.01	2.22 ± 0.01
^{14}C	A	$3.0 \pm 0.3 \times 10^{-12}$	NA
	W	$3.0 \pm 0.1 \times 10^{-7}$	NA
	F	$5.7 \pm 0.3 \times 10^{-9}$	NA
^{60}Co	A	$2.2 \pm 0.2 \times 10^{-11}$	$8 \pm 1 \times 10^{-10}$
	W	$1.4 \pm 0.2 \times 10^{-7}$	$8 \pm 1 \times 10^{-8}$
	F	$1.1 \pm 0.2 \times 10^{-8}$	$6 \pm 2 \times 10^{-9}$
^{134}Cs	A	$8 \pm 1 \times 10^{-12}$	$2.4 \pm 0.8 \times 10^{-12}$
	W	$6 \pm 1 \times 10^{-8}$	$2 \pm 1 \times 10^{-8}$
	F	ND	ND
^{137}Cs	A	$4.2 \pm 0.1 \times 10^{-10}$	$1.6 \pm 0.1 \times 10^{-10}$
	W	$3.2 \pm 0.1 \times 10^{-6}$	$1.8 \pm 0.1 \times 10^{-6}$
	F	$8 \pm 2 \times 10^{-9}$	$5 \pm 2 \times 10^{-9}$

* Sample types: A - air filter; W - water passed through 0.45-μm membrane filters; F - 0.45-μm filters through which water sample was passed.

± Values indicate analytical error at 2-σ confidence level.

NA No analysis. Above samples were not analyzed for ^{90}Sr and Pu concentrations.

ND Not detectable.

Table 4.5

Gaseous ^{14}C in Samples of Evaporator Stack Effluent, $\mu Ci/ml$

		^{14}C Concentration	
Test No.	Sample	CO_2	Non-CO_2
21	1	$1.6 \pm 0.4 \times 10^{-8}$	$<4 \times 10^{-9}$
21	2	$<4 \times 10^{-9}$	$<3 \times 10^{-9}$
22	1	$<4 \times 10^{-9}$	$<4 \times 10^{-9}$
22	2	$<1 \times 10^{-8}$	$<8 \times 10^{-9}$

Table 4.6

Radionuclide Discharge Rates from Evaporator Stack during Tests 18 - 22 ($\mu Ci/sec$)

	Test No.				
Radionuclide	18	19	20	21	22
^{3}H	7.8 (1)	5.7 (1)	6.0 (1)	9.5 (2)	1.8 (3)
^{14}C	1.2 (-4)	2.5 (-4)	9.2 (-5)	2.5 (-4)	NA
^{58}Co	6 (-7)	4.9 (-5)	ND	ND	ND
^{60}Co	3.6 (-5)	1.0 (-4)	3.6 (-5)	1.4 (-4)	7.4 (-5)
^{90}Sr	5.6 (-5)	7.7 (-5)	5.1 (-5)	NA	NA
^{134}Cs	2 (-5)	2.0 (-5)	2 (-5)	6 (-5)	2 (-5)
^{137}Cs	1.2 (-4)	7.0 (-4)	1.4 (-4)	3.0 (-3)	1.6 (-3)
^{238}Pu	2.4 (-6)	3.3 (-5)	5.4 (-6)	NA	NA
^{239}Pu	ND	4.5 (-7)	6 (-8)	NA	NA

Exponents of 10 are indicated by numbers in parentheses.

NA Not analyzed.

ND Not detectable.

Table 4.7

Concentrations of Radionuclides in Evaporator Input Samples

(μCi/ml)

Liquid Source	Radionuclide	Dissolved Solids	Suspended Solids
Tank J	^{14}C	$4.5 \pm 0.1 \times 10^{-6}$	NA
	^{60}Co	$2.0 \pm 0.2 \times 10^{-6}$	$6.3 \pm 0.2 \times 10^{-7}$
	^{137}Cs	$2.0 \pm 0.2 \times 10^{-6}$	$1.0 \pm 0.1 \times 10^{-6}$
	^{238}Pu	$9.3 \pm 0.7 \times 10^{-6}$	$3.5 \pm 0.02 \times 10^{-5}$
	^{239}Pu	$4.7 \pm 1.3 \times 10^{-8}$	$1.9 \pm 0.3 \times 10^{-7}$
Dilution Water	^{14}C	$< 5 \times 10^{-8}$	NA
	^{60}Co	$1.3 \pm 0.3 \times 10^{-7}$	$4.9 \pm 0.2 \times 10^{-7}$
	^{137}Cs	$8.5 \pm 2.8 \times 10^{-8}$	$8.6 \pm 1.0 \times 10^{-8}$
	^{238}Pu	$2.7 \pm 0.1 \times 10^{-7}$	$5.8 \pm 0.3 \times 10^{-7}$
	^{239}Pu	$2.0 \pm 0.7 \times 10^{-9}$	$6.7 \pm 1.0 \times 10^{-9}$
Tank A	^{14}C	$1.2 \pm 0.04 \times 10^{-5}$	$5.0 \pm 0.1 \times 10^{-7}$
	^{60}Co	$1.3 \pm 0.02 \times 10^{-5}$	$5.2 \pm 0.3 \times 10^{-7}$
	^{137}Cs	$4.7 \pm 0.1 \times 10^{-6}$	$5.3 \pm 1.8 \times 10^{-8}$
Tank F	^{14}C	$5.9 \pm 0.2 \times 10^{-6}$	$6.6 \pm 0.3 \times 10^{-8}$
	^{60}Co	$1.5 \pm 0.1 \times 10^{-6}$	$6.3 \pm 0.3 \times 10^{-7}$
	^{137}Cs	$1.1 \pm 0.01 \times 10^{-5}$	$2.9 \pm 0.2 \times 10^{-7}$

± Values indicate analytical error at 2-σ confidence level.
NA Not analyzed.

Table 4.8

Decontamination Factors of Waste Processing System

Radionuclide	Test No. 19	20	21	22
^{14}C	–	22	23	–
^{60}Co	11	40	–	41
^{137}Cs	3	13	–	5
^{238}Pu	–	3670	–	–
^{239}Pu	–	1710	–	–

5. SUMMARY

Additional measurements were conducted on-site and in the environment of the Maxey Flats radioactive waste burial site near Morehead, Kentucky. These measurements, somewhat limited in scope and number, were for the purpose of supplementing data acquired during 1974-1975 and published in 1977. The objectives of these measurements, the results, and interpretations are discussed below.

1. Additional samples of vegetables (tomatoes) and milk, determined during the 1974-1975 study as the most significant foods for the potential exposure of people living near the site, were analyzed. Results confirmed the earlier observations that ^{3}H is the only measurable radionuclide present and that the radiation dose resulting from consuming these foods is very low. The observation that ^{3}H levels in milk from cows drinking Rock Lick Creek water were lower in 1976 than in 1975 indicates that levels of radioactivity in surface run-off from the site has decreased. No difference in ^{3}H levels in tomatoes was observed between 1974-1975 and 1976. This was expected since the source of the ^{3}H was the evaporator which operated in a similar fashion during both study periods. Evaporator operation was not reduced to 40 hr/wk until August 30, 1976, the end of the tomato growing season and sampling period.

2. Low-level contamination of land surfaces with ^{3}H resulting from evaporator operations will continue for as long as this means is necessary to dispose of accumulated trench water. Since its inception in 1973, more than 2.6 million gallons (1×10^{7} liters) of trench water containing an estimated average of 1×10^{9} pCi/l of ^{3}H have been processed.(12) Thus, the quantity of ^{3}H discharged by the evaporator probably exceeds 10,000 curies. During August 1976, the evaporator operation was reduced from a 24-hr/day, 5-day/wk schedule to an 8-hr/day, 5-day/wk schedule. This curtailed operation should result in lower annual discharges of ^{3}H.

3. Thirteen auger-cutting samples obtained from holes augered to depths of 1.5 to 3.5 m below ground level in the vicinity of trenches 10, 15, 35, 41, 11S and 19S contained only small quantities of radioactivity that decreased sharply with depth. The observed radioactivity was probably due to surface contamination. The ground surface in the sampling area had been disturbed to some extent by burial operations, which probably explains the existence of some radioactivity at 2 to 3 m depths. It is doubtful that any significant amount of the radioactivity observed can be attributed to subsurface migration from the near-by trenches. However, this does not discount the possible occurrence of deeper subsurface movement of radioactivity from the trenches through fissure systems in the underlying rocks.

4. A test well sample was examined to determine what fraction of the plutonium present was associated with particulate matter and the size of the particles on which it was attached. The results indicated that essentially all of the radioactivity ($> 99.8\%$) was associated with particulate matter, with the smallest particle-size fraction containing the highest concentration. These data indicate that if this radioactivity, particularly plutonium, originated in the trenches, it was transported to the test wells through fissures in the rock attached to particles or possibly as a mobile organic complex which for some reason was destroyed immediately upon reaching the test well. If the latter is true, it is surprising that at least some plutonium is not present in the soluble fraction. Also, the agent responsible for breaking down the organic plutonium complex is unknown. Test-well water should be analyzed for evidence of organic compounds that have been observed in trench water. These include numerous aliphatic and aromatic acids, alcohols, ketones, esters and ethers.(3) Another possibility is that test-well sediment may be contaminated by large volumes of water, containing radionuclides at concentrations below detectable levels, that percolate through rock intersected by the well.

5. Concentration of radionuclides in evaporator effluent and leachate input to the evaporator system were measured on five occasions in 1976 and 1977. The objectives of these measurements were to improve the DF values previously determined and to include ^{14}C which was not previously measured. The DF's were variable and generally lower than those previously measured. Recommended DF's for use in estimating stack effluent concentrations are given below. DF's determined in Test 6 and the two ^{137}Cs values of less than one (Tests 16 and 17) were neglected in arriving at these suggested values (See Table 2.12 of reference 1).

$^{14}C = 22$	$^{90}Sr = 250$	$^{134,137}Cs = 40$
$^{60}Co = 90$	$^{106}Ru = 80$	$^{238}Pu = 1.5 \times 10^{5}$

6. The radiation dose resulting from atmospheric discharges of ^{14}C was insignificant, less than 0.001 mrem/yr to the lung and GI tract. It is apparent that ^{3}H is the critical radionuclide in evaporator effluent, delivering an estimated 0.8 mrem/yr (total body) to the limiting receptor, assuming the 40-hr/wk operating schedule continues. All other radionuclides discharged, including plutonium, contribute less than 0.1 mrem/yr to the limiting receptor.

7. The results of four years of study, although limited in scope, described in this and the previous report,(1) verify with little question that individuals in the vicinity of the Maxey Flats burial site are not exposed significantly to radiation from the burial site. Considering the small radiation doses computed from measurements made during these studies and the limited population involved, no apparent health effects can be expected. However, to better understand other aspects of shallow burial of radioactivity and to gain an insight into the potential long-term impact of this and similar burial sites, necessary for establishing criteria for setting appropriate radiation standards, the following additional short-term projects are suggested:

    a. Evaluate the significance of ^{14}C emanating as gasses from buried wastes.

    b. Measure external gamma-ray radiation on and off site.

    c. Measure evaporator plume depletion during rainfall and ground-level ^{3}H concentrations beneath the plume at various distances and relate these measurements to available atmospheric transport models.

    d. Repeat surface water/sediment sampling to ascertain changes in radionuclide distribution with time.

    e. Determine if organics prevalent in trench leachate are present in test-well water.

    In addition, a continuous water sampling station installed on Rock Lick Creek at the USGS gauging station would provide data to estimate the quantity of radioactivity leaving the burial site via the aqueous pathway.

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APPENDIX 2. ^{14}C DOSE COMPUTATION

The annual radiation dose from ^{14}C in evaporator effluent to the limiting receptor is given by:

$$\text{Dose (mrem/yr)} = 8.4 \times 10^{6}\ (\text{DCF})\ (\overline{\chi})/4,$$

where,

DCF = dose conversion factor [taken from Killough and McKay (1)]

Soluble form - 1.07×10^{-4} rem/μCi to the GI tract,

Insoluble form - 5.94×10^{-2} rem/μCi to the lung,

4 = adjusts the dose to a 40 hr/wk discharge

$\overline{\chi}$ = ground-level air concentration of ^{14}C at the site of the limiting receptor, given by

3.3×10^{-6} Q.(2) Q is the evaporator stack discharge rate, and given by:

$$Q = C \times FR/DF,$$

where,

C = average ^{14}C concentration in the holding tanks; assumed to be 1.9×10^{-5} μCi/ml.

FR = feed rate to the evaporator stack; 284 ml/sec.

DF = decontamination factor; assumed to be 22.

See Appendices 4 and 5 of previous report for further details.(2)

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